ON THE DISTRIBUTION OF GROWTHS IN SURFACE WATER-SUPPLIES AND ON THE METHOD OF COLLECTING SAMPLES FOR EXAMINATION

BY FREDERICK S. HOLLIS

WITH FOUR PLATES

The purpose of the study of the micro-organisms floating in a body of water may be two-fold. It may be conducted for purely scientific information or for practical purposes, as a means of determining the total amount of material which is available as food for higher forms of life, or the results of the study may be used as a guide in properly conducting a system of water works. In the case of the study of the micro-organisms in connection with water-supplies, they are to be regarded as deleterious, and the determination of the exact position and recurrence of growths becomes of the utmost importance as a means of avoiding them.

For such practical ends in this connection, the determination of the micro-organisms is only a part of the necessary study, and such determinations should be supplemented by chemical and bacteriological examinations of the water. The micro-organisms are, indeed, to be considered only as a phase or form of the organic contents of the water, which, in this form, is objectionable as a source of odor and taste caused either by the characteristic odor of growth of the particular form or resulting from its decay, and as a source of food which will during its decay give rise to an abnormally large bacterial growth. The relation between the micro-organisms and the other forms of impurities of a water is best seen in a study of the nitrogen contents of the water. Starting, say with an organic growth, the nitrogen is in combination with the other constituents of the organic bodies and appears in the chemical analysis as albuminoid ammonia. After the death of the organism it becomes disengaged as a result of decomposition and exists, first as free ammonia and, as the

result of various states of oxidation, as nitrites and nitrates, in which last stage it is available as plant food to be built up again into organic bodies.

Individual samples must be taken for the chemical and bacteriological examinations and, in order that the comparison may be made between the organic life and the impurities in the other forms, the samples for microscopical examination must be identical with those taken for the other examinations.

Microscopical examinations have been made for the past ten years of the water of the reservoirs of the Massachusetts Metropolitan Water Works, which passed from the control of the City of Boston on January 1st, 1898. Samples are taken regularly once a week from the surface, mid-depth and bottom at the deepest point of the reservoirs, which is commonly near the gate-house or outlet. These results have been supplemented, when necessary, by samples taken every few feet and, during periods of growth, by regular inspection of the sources and the collection of samples at various parts of the reservoir, as a means of determining the rate of extension of growths through the reservoir.

Chemical samples are taken less frequently and also occasional bacterial samples at the surface, mid-depth and bottom for comparison.

The results obtained from the samples collected in this way and their usefulness as a means of avoiding growths which would be objectionable if taken into the distributing reservoirs have convinced us that the information which is most to be desired is best obtained from such samples.

The samples for the microscopical and chemical examination are taken by lowering a collecting bottle to the desired depth in a weighted cage and, by means of a separate cord, withdrawing a cork stopper which has been substituted for the ground glass stopper. The neat form of collecting cage in which a spring releases the stopper, thus making unnecessary a separate cord, was devised by Mr. G. C. Whipple.

The eight reservoirs of the Metropolitan Water Works offer uncommon advantages for the study of the surface water of that section of New England. Each receives surface water colored more or less according to the season of the year by the peaty matter of the valley through which the influent flows, but almost entirely free from the turbidity

caused by the presence of clay, which is noticed in other sections of the country. Such slight turbidity as is caused by the spring rains is due largely to the presence of fine sand or rock flour and subsides so quickly that it rarely reaches the outlet end of the reservoir.

Lake Cochituate is formed of a chain of three lakes which were deepened considerably by building a dam across the outlet of the lowest one fifty years ago, when water was first taken from this section for the supply of the City of Boston.

Whitehall Reservoir was also formed by enlarging a natural pond, but it is deepened to such an extent that it is practically an impounding reservoir. Framingham Reservoirs Nos. 1 and 2 were formed by constructing dams across the main stream of the Sudbury River.

Sudbury Reservoir, Framingham Reservoir No. 3 and the Ashland and Hopkinton Reservoirs were formed by building dams across the various feeders of the Sudbury River.

Water from the south branch of the Nashua River, which will eventually be impounded in the largest reservoir of the series, has been collected for more than two years by means of a temporary dam and deflected to the Sudbury Reservoir, the largest present member of the series, of which it has become the principal feeder.

	Contents in billion gallons.	Depth, when filled, at deepest point.
Lake Cochituate	2.9	60 ft.
Framingham Reservoir No. 1	0.3	15 ft.
Framingham Reservoir No. 2	0.5	17 ft.
Framingham Reservoir No. 3	1.2	21 ft.
Sudbury Reservoir	7.6	about 55 ft.
Hopkinton Reservoir	1.5	about 52 ft.
Ashland Reservoir	1.4	49 ft.
Whitehall Reservoir	1.6	25 ft.

The water from the Nashua River, together with that collected from the water shed of the Sudbury Reservoir passes, after storage for a considerable period, through Framingham Reservoir No. 3, the next lower reservoir of the series, to the entrance of the pipe line and aqueduct leading to Chestnut Hill Reservoir. Water from the other reservoirs passes through Framingham Reservoir No. 1 and to the same

aqueduct. A separate aqueduct leads from Lake Cochituate to Chestnut Hill Reservoir. From Chestnut Hill Reservoir it runs directly to Boston in pipes or is pumped to the various distributing reservoirs of the Metropolitan district.

All save Lake Cochituate and Whitehall Reservoirs have gates for drawing the water from both the surface and bottom, and the deeper and more important ones have also a gate at the mid-depth.

The surface soil has been completely removed from the entire area of the more important reservoirs, and in some cases the influent streams have been diverted from the swampy areas, which caused an increase of color, by ditching. The water of a few of the brooks, more likely to be contaminated than the others, is filtered before it is received into the reservoirs.

All of the examinations have been made by the Sedgwick-Rafter method which commends itself because of its accuracy and the comparatively small factors used in converting the recorded results of the observations into standard units per cc. The Jackson funnel is used and the degree of concentration most commonly employed is 500 to 10. All results are expressed in terms of the standard unit per cc. (1 standard unit=400 sq. microns) as proposed by Mr. G. C. Whipple.

Results expressed in standard units per cc. are an approximation to a quantitative estimation in which the same number of standard units of the different forms express as nearly as possible equal amounts. Results so expressed agree more closely with the results of chemical analysis than those expressed in numbers per cc., and are to be preferred greatly for accuracy and usefulness.

From a study of the growths of the principal reservoirs it is seen that they may be divided into groups which show a different development and distribution of growths. In those in which water is collected and held until used, the water is quiescent except for the action of the wind and the overturn at spring and autumn due to temperature changes. In such reservoirs the development of the growths is a normal one and, in general, a marked difference is noticed between the abundance of the organisms at different depths.

In those in which the water passes through the reservoir at a considerable rate, growths are brought in and mingled with those of the reservoir and a normal development is prevented by the circulation of the water.

On the accompanying plates this is shown by the average of weekly analyses from 1895-9 inclusive for six of the reservoirs. (Plates V and VI.)

Calling the average number of organisms for the year of each source at the surface as 100, the following table shows the average yearly number of organisms of the mid-depth and bottom of each source expressed in percentages of the surface growth:

	Surface		Mid-depth		Bottom	
	Organisms	Per cent. of surface	Organisms	Per cent. of surface	Organisms	Per cent. of surface
Sudbury Res.	339	100	226	67.5	169	49.2
Hopkinton Res.	550	100	276	50.2	214	38.9
Ashland Res.	178	100	123	69.1	95	53.5
Lake Cochituate	672	100	576	84.9	608	88.0
Fram. Res. No. 2	158	100	143	90.5	107	67.9
Fram. Res. No. 3	581	100	510	87.7	487	83.8

The Sudbury, Hopkinton and Ashland Reservoirs belong to the first group in which normal growths are possible and do occur. Framingham Reservoirs No. 2 and 3 are as ordinarily conducted members of the second group. The organisms of Framingham Reservoir No. 3 have been much lower since water has been supplied from the Sudbury Reservoir and the Nashua River than when filled with water from its own water shed.

Lake Cochituate, while it would seem to fall under the second group, does, in reality, belong as far as most of the growths are concerned to the group in which there is a normal development of growths. Several causes act to make the average number of organisms irrespective of species similar at the surface, mid-depth and bottom. The lake at its deepest point where samples are collected is sixty feet deep and the bottom at this point is such that marked stagnation effects follow the quiescent state of the water during the summer and to a lesser extent during the winter when the surface is covered with ice. When the water at the surface reaches the temperature of greatest density which commonly happens in November and again in the spring soon after the ice leaves the reservoir, there is a complete mixing of the water of all depths.

Crenothrix, which has become abundant at the bottom, is brought up and distributed quite evenly throughout the water at all depths.

The food material which has accumulated at the bottom during the period of stagnation is also distributed throughout the water by the overturn, thus supplying abundant food for the support of a large diatom growth, which has commonly commenced before the time of the overturn. As the water remains in circulation until the surface water becomes enough colder to make it less dense than that of the lower layers, the diatom and other growths become generally quite evenly distributed.

One of the characteristics of the stagnant layer of water is a marked increase of color.

The temperature and color at the surface, mid-depth and bottom of Lake Cochituate for a year, indicating the quiescent state and the spring and autumn overturns are given on the accompanying plates. (Plates VII and VIII.)

The distribution of the micro-organisms before and at the time of the autumn overturn of the water for the same year is shown by the following analyses:

LAKE COCHITUATE—1896

DATE	SURFACE					MID-DEPTH					BOTTOM				
	Total Organisms	Diatomaceae	Cyanophyceae	Infusoria	Crenothrix	Total Organisms	Diatomaceae	Cyanophyceae	Infusoria	Crenothrix	Total Organisms	Diatomaceae	Cyanophyceae	Infusoria	Crenothrix
Oct. 20......	476	333	72	27	00	397	293	26	33	4	56	54	0	0	0
Oct. 27......	446	235	258	7	70	574	289	180	29	58	483	258	42	3	174
Nov. 3......	762	645	34	43	0	638	568	18	27	20	849	357	0	16	428
Nov. 9......	742	677	26	26	8	880	783	36	17	10	655	422	0	28	152
Nov. 16.....	1279	805	334	25	114	1344	1004	250	40	50	1319	1223	28	0	88
Nov. 23	2016	1725	188	17	78	1924	1576	256	17	50	1701	1425	228	18	36
Nov. 30.....	1479	1218	200	47	10	1319	1039	258	7	12	1304	1156	84	36	28
Dec. 7......	1980	1633	258	63	26	1762	1502	200	13	10	1761	1506	228	5	14
Dec. 14.....	1876	1570	182	104	4	1454	1288	76	68	0	1739	1524	861	26	20

That the amount of water at the bottom of the lake in which these stagnation effects are marked is insignificant compared with the whole volume of the water is evident from the very slight increase of color imparted by the water of the stagnant layer to the water of the other depths at the time of the overturn.

As has been stated, the surface soil has been removed from the entire area of most of the reservoirs and in these the stagnation effects and the collection of food material at the

bottom is very slight, although the same dissemination of organisms throughout the different depths at the time of the overturn is noted as in the case of Lake Cochituate.

DIATOMACEAE

In Lake Cochituate, as a result of this mixing of the diatoms at all depths by the spring and autumn overturn of the water during the time of development of the diatom growths, together with a considerable local growth of Melosira at the bottom, the average diatom growth for 1898 and the first month of 1899, during which time the autumn growth continued, was as follows: Surface, 326; mid-depth, 358; bottom, 372.

The same tendency is shown in the Sudbury Reservoir toward a more uniform number of diatoms at all depths due to the mixing at the time of the overturn, although all the conditions are favorable for a normal development. The average for the year 1897 was 84 at the surface, 81 at the mid-depth and 61 at the bottom. For the period between the first of May and the first of December, 1899, the average for this source was 329 at the surface, 283 at the mid-depth and 199 at the bottom.

Aside from Lake Cochituate but few of the reservoirs of the Metropolitan supply support diatom growths which are ever large enough to be seriously detrimental to the character of the water. Furthermore, while the average for the year may be so influenced by the large numbers which follow the period of overturn and extend to all depths, there are many diatom growths during the year where there is, for part of the period of growth at least, a marked tendency to local development at a particular depth, in which case the forms can frequently be avoided, along with the other growths, by drawing the water from a depth at which the diatom growth does not exist.

Such a growth is Asterionella, which commonly develops in largest numbers at or near the surface. I recall one instance of a surface growth of Asterionella amounting to about 250 stand. units per cc. in a comparatively small reservoir 30 ft. deep in a hilly or almost mountainous district in Pennsylvania, which was entirely washed from the reservoir over the spill-way by a single heavy rain, during a period when I was studying the supply.

Most of the diatoms impart an oily or aromatic odor and taste to the water which is characteristic of the form, but generally not particularly well marked. This odor is generally increased somewhat by heating.

Asterionella is an exception and is characterized by a well-marked distinctive aromatic odor resembling rose-geranium leaves, which is frequently lost by heating.

The forms of most importance in determining the purity of a water-supply are found among the Cyanophyceae, and Infusoria and to a lesser extent among the Chlorophyceae and Rotifera. These undoubtedly all tend to a local development during the period of maximum growth in a reservoir in which the conditions are such that a normal growth is possible.

CYANOPHYCEAE

Of the Cyanophyceae, Anabaena is perhaps the most common and the most objectionable form, as it develops in large numbers and imparts its characteristic choky odor and unpleasant taste to the water and the odor is much intensified by heating. It tends under normal conditions to a maximum development during the period of growth at the surface, where it collects in large numbers in areas which are moved about the surface of the reservoirs by the action of the wind. It is frequently mixed through the water by heavy winds or by the flow of a large volume of water through a reservoir, but, if in a vigorous growing condition, it tends to rise again to the surface.

In the Sudbury Reservoir during a period of growth from the middle of August to the middle of September, 1897, the average was 346 at the surface, 81 at the mid-depth and 18 at the bottom, with a maximum growth of 684 at the surface.

For the same source for the period of growth between the middle of May until the first of November, 1899, the average for the surface was 121, for the mid-depth 69 and for the bottom 48, with a maximum growth of 648 at the surface in August.

The same is true for Framingham Reservoir No. 3, Lake Cochituate and the other sources in which it develops. The largest growth of Anabaena that has ever come to my attention was one in the same Pennsylvania reservoir in which the growth of Asterionella was noted, where it showed the

same tendency to a maximum development at the surface. The samples were taken July 27, 1897, and showed 5,100 at the surface, 670 at the mid-depth and 123 at the bottom.

Clathrocystis is another form of Cyanophyte which is quite generally distributed and causes difficulty in a supply by imparting a sweetish odor and taste suggestive of the husks of green corn to the water. Its distribution is best studied in the Hopkinton Reservoir in which it has reached large numbers in recent years. The most abundant growth occurs betwween June and November. Like Anabaena it tends to grow at the surface and to form patches.

The averages for the periods of growth for the last three years and the maximum growth at the surface are as follows:

	Surface	Mid-Depth	Bottom	Maximum Growth at Surface	
1897	1644	645	693	3460	August 10
1898	824	246	46	2900	June 28
1899	386	75	48	2000	June 20-27

Coelosphaerium, while quite as widely distributed as Clathrocystis, is not, however, as objectionable. It is present with the growth of Clathrocystis in the Hopkinton Reservoir and between May and November of last year showed an average of 144 at the surface, 98 at the mid-depth and 102 at the bottom.

A growth in Framingham Reservoir No. 3, between May and October, 1895, showed an average of 489 at the surface, 469 at the mid-depth and 412 at the bottom.

It tends to grow at the surface and to collect in masses as do the other members of this group but, on account of its more compact structure, it seems more apt to remain at a depth when carried there by the action of the wind.

Aphanizomenon, which occurs as large growths only in Lake Cochituate, imparts a characteristic sweetish taste to the water which is not, however, as objectionable as that of the other Cyanophyceae already described. The growth commences at a depth and is first noted at the mid-depth and bottom during July. The maximum growth is at the surface, where it is very abundant in the form of flocks, and generally occurs late in November or during December. As the growth is well developed at the time of the autumn overturn it is generally quite well distributed at all depths.

The growth in 1898, which was rather larger than usual, appeared at the mid-depth and bottom on June 27, reached

a maximum of 1385 per cc. at the surface on December 12, and continued until February 6 of the following year. The average for the period of growth was 318 at the surface, 220 at the mid-depth and 144 at the bottom.

Microcystis is frequently abundant and attains a large growth at the bottom as well as at other depths. It is, however, not objectionable in the quantity in which it is found in our reservoirs.

Oscillaria is observed floating in flakes attached to thin plates of mud after it has risen to the surface. Its presence has never given rise here to any objectionable condition of the water.

CHLOROPHYCEAE

Among the Chlorophyceae, the floating forms that are met develop maximum growths at the surface. Their presence has never caused any objectionable qualities in the water of our reservoirs.

Protococcus is of very common occurrence at certain seasons of the year, but is rarely abundant.

A growth in the Sudbury Reservoir between July 7 and October 27, 1897, amounted to an average of 53 at the surface, 24 at the mid-depth and 7 at the bottom.

Gonium has at times been quite abundant at the surface of part of the Sudbury Reservoir.

Spirogyra, Conferva and Draparnaldia are common as growths along the lower course of the influent streams, but they are rarely met in samples of water taken at the lower end of the reservoir.

DESMIDEAE

Among the Desmideae, Staurostrum is the only form that is ever found in any abundance in the main body of water of the reservoirs. Its presence has never caused trouble. Other members are common in the influent streams and detached shallow portions of water.

The presence of Crenothrix is characteristic of the stagnation effects at the bottom of a reservoir and, unless washed in in large numbers from adjoining swamps, is present in the main body of water only after an overturn of the water.

INFUSORIA

The Infusoria are perhaps the most objectionable forms encountered in water-supplies, both on account of the objection-

able odor and taste imparted to the water by many of them and on account of their universal distribution and very rapid development. The more objectionable ones tend to develop in large numbers at or near the surface, but are frequently distributed through the water and, during the decline of a growth, they frequently collect near the bottom of a reservoir.

Uroglena is frequently present in large numbers between early autumn and the following summer, and imparts a strong and unpleasant oily odor and taste strongly suggestive of whale oil soap to the water. This odor is much intensified by heating. Normally, it tends to develop in greatest abundance at the surface. Such a normal growth is just disappearing from Lake Cochituate. The average number of Uroglena between May 17 and June 18 was 973 at the surface, 157 at the mid-depth and 86 at the bottom, with a maximum growth of 3800 at the surface on May 31.

The largest growth at Uroglena noted in our reservoirs was in Framingham Reservoir No. 3 in 1897, at a time when the water of the reservoir was uniformly turbid as the result of work in progress on a reservoir above it on the same water shed.

The growth extended to all depths from the time of its appearance and lasted from May 12 to June 23, 1897. The average at the surface was 2178, at the mid-depth 2288 and at the bottom 2696, with maximum growth of 4700 at the surface and mid-depth.

It is not uncommon for Uroglena, when seeded into a storage reservoir, to develop to such an extent as to be higher in the water thus contaminated than in the original source.

Synura is another form which may be expected at almost any time of the year except during the most extreme heat of summer, although it is most common in cold weather. It imparts a characteristic and unpleasant taste and odor to the water and this is intensified by heating.

Like Uroglena, it is capable of increasing rapidly if seeded into a reservoir from a contaminated source. Normally it tends to develop in largest numbers near the surface, but a vigorous growth generally extends to a considerable depth.

A growth in the Sudbury Reservoir between the first of April and the middle of May showed an average of 31 at the surface, 27 at the mid-depth and 1 at the bottom, with a maximum growth of 134 at the surface on May 5.

A considerable Synura growth in Lake Cochituate in 1897 was distributed as follows:

		Stand. units per cc. of Synura	Taste of Water	Taste of Concentrate
Feb. 7	Surface	286	Synura taste	Strong Synura taste
Feb. 8	Surface	116	Synura taste	Strong Synura taste
	5 ft.	144	Synura taste	Strong Synura taste
	10 ft.	74	Synura taste	Strong Synura taste
	15 ft.	64	Synura taste	Strong Synura taste
	20 ft.	48	Synura taste	Synura taste
	25 ft.	32	Slight Synura taste	Slight Synura taste
	35 ft.	0	No Synura taste	No Synura taste
	45 ft.	10	No Synura taste	No Synura taste
	55 ft.	42	Slight Synura taste	Synura taste

Dinobryon, Glenodinium, Peridinium, Chlamydomonas and Mallomonas have been noted in considerable numbers and all impart an odor and taste to the water.

The first three give it an oily odor which is increased by heating. Chlamydomonas causes an oily odor when present in moderate numbers and a disagreeable odor when very abundant. Mallomonas when very abundant imparts an odor suggestive of violets.

Dinobryon and Glenodinium reach the highest numbers at the surface, but are frequently present in large numbers at lower depths, especially during the decline of the growth.

Peridinium, while common at the surface, is frequently found in abundance at the lower depths.

Chlamydomonas has been observed in large numbers but once in any of our reservoirs. From August, 1898, to late in the spring of the following year it was present in considerable numbers and, while mainly a surface growth, it was present to the extent of about 150 at the surface, middepth and bottom when it reached its maximum growth in March, 1899.

Mallomonas is of frequent occurrence, but has never been the cause of trouble. It is a form which develops at a considerable depth and is brought to the surface by the circulation of the water. It tends to settle back to its original position. Lake Cochituate and Whitehall Reservoir have shown the most marked growth. It was brought to the surface of one portion of Whitehall Reservoir to the extent of 2168 standard units per cc. by a wind storm in August, 1897. Four days afterwards the maximum growth of 1936 standard units per cc. was found at a depth of 10 feet. On the middle of September it was all near the bottom.

ROTIFERA

Rotifera are frequently quite abundant, but not often to an extent sufficient to influence the character of the water. While the largest growths are generally at the surface, it is not uncommon for them to appear first at the bottom of a reservoir. Their appearance seems often to follow a growth of Infusoria. Polyarthra, Synchaeta and Anuraea are the forms most commonly observed.

It has been impossible for me, in the short space of time that I have been able to allow myself for the preparation of this paper, to make a sufficient number of averages from the occurrences of the different growths to give the results the definiteness at which I had aimed. Such as I have made are, however, selected carefully from the great mass of accumulated results as types, and have been worked out for periods of a considerable length of time. Many averages not here given have been prepared from the results of the other sources and have served merely to confirm the ones selected, which better represent the typical growths.

They are, therefore, only types of the many hundred that might be produced in the case of any of the forms more commonly met, and will, I think, justify the following conclusion:

With reservoirs properly constructed, from which the surface soil has been removed, so that marked stagnation effects are avoided, with outlets at the surface, mid-depth, and bottom, and so arranged that an individual reservoir can be cut out of the chain in case of contamination from a growth, it is possible by watching the water through the regular examination of samples from the surface, mid-depth and bottom and well directed field work, as a means of tracing the development of a growth through a reservoir, to avoid almost entirely the results of such growths. Such information enables one to fill one reservoir from another when the water thus stored for future use is in its best condition and to supply water for consumption as free from growths as the nature of the supply permits.

Even with reservoirs less carefully constructed and less fortunately situated than those of the present Metropolitan supply, much can be accomplished by such study of the sources.

Laboratory of the Metropolitan Water Works,
Boston, Mass., June 26, 1900.

EXPLANATION OF PLATES

Plate V

Graphic representation of the average of weekly analysis from 1895 to 1899, inclusive, to show the abundance of organisms at surface, mid-depth and bottom for Sudbury, Hopkinton and Ashland reservoirs.

Plate VI

The same for Framingham reservoirs Nos. 2 and 3 and for Lake Cochituate.

Plate VII

Graphic representation of yearly record of temperatures in Lake Cochituate for 1896, showing the quiescent state and the spring and autumn overturns.

Plate VIII

The same for color in Lake Cochituate during 1896.

PLATE V

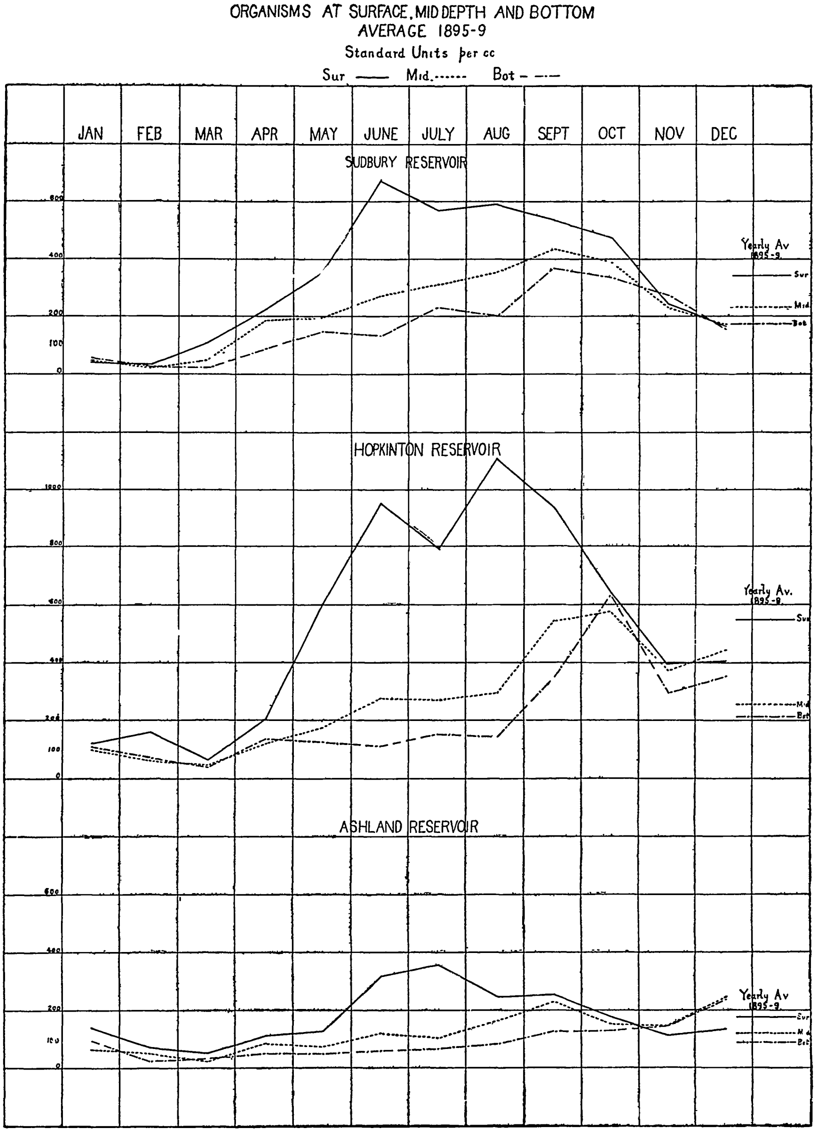
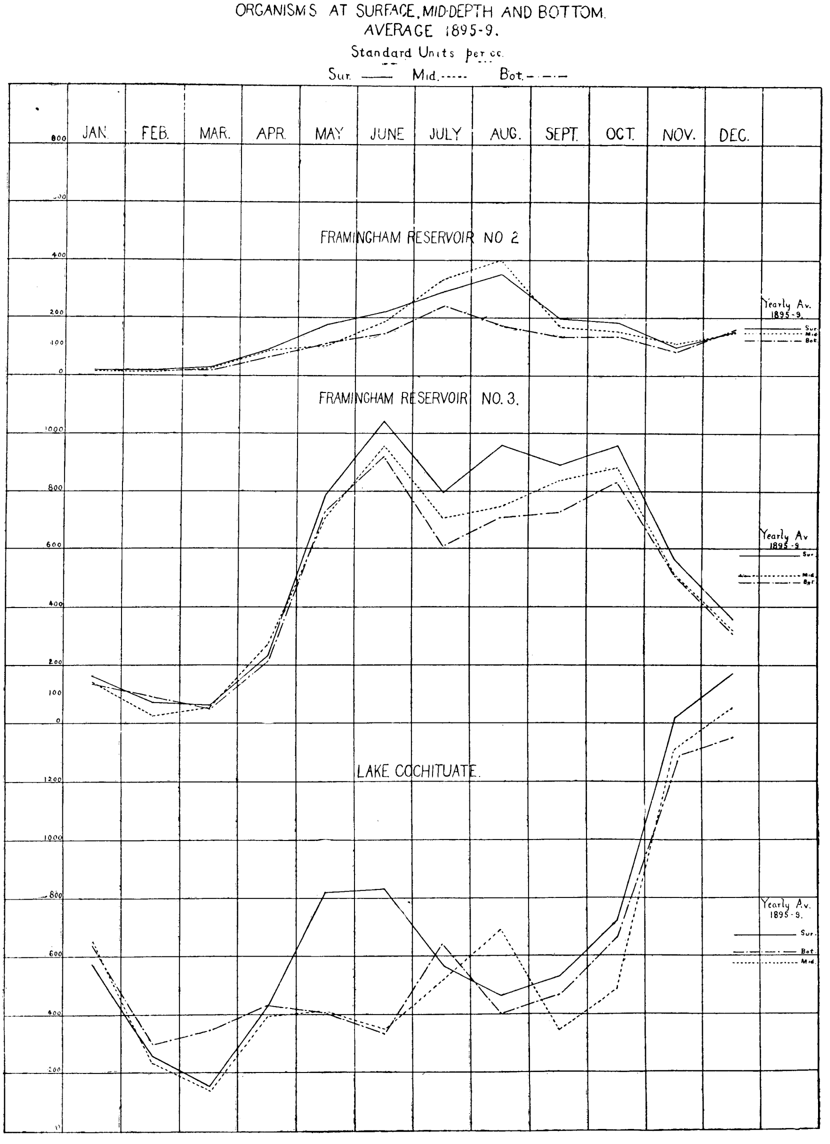

ORGANISMS AT SURFACE, MID DEPTH AND BOTTOM
AVERAGE 1895-9
Standard Units per cc
Sur —— Mid. ------ Bot – —·–
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
SUDBURY RESERVOIR
HOPKINTON RESERVOIR
ASHLAND RESERVOIR
Yearly Av 1895-9.
Sur
Mid
Bot

PLATE VI



ORGANISMS AT SURFACE, MID-DEPTH AND BOTTOM.
AVERAGE 1895-9.
Standard Units per cc.
Sur. —— Mid.----- Bot.-·-·-
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
FRAMINGHAM RESERVOIR NO 2.
FRAMINGHAM RESERVOIR NO. 3.
LAKE COCHITUATE.
Yearly Av. 1895-9.
Sur.
Mid.
Bot.
800
400
200
100
0
1000
800
600
400
200
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1200
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PLATE VII

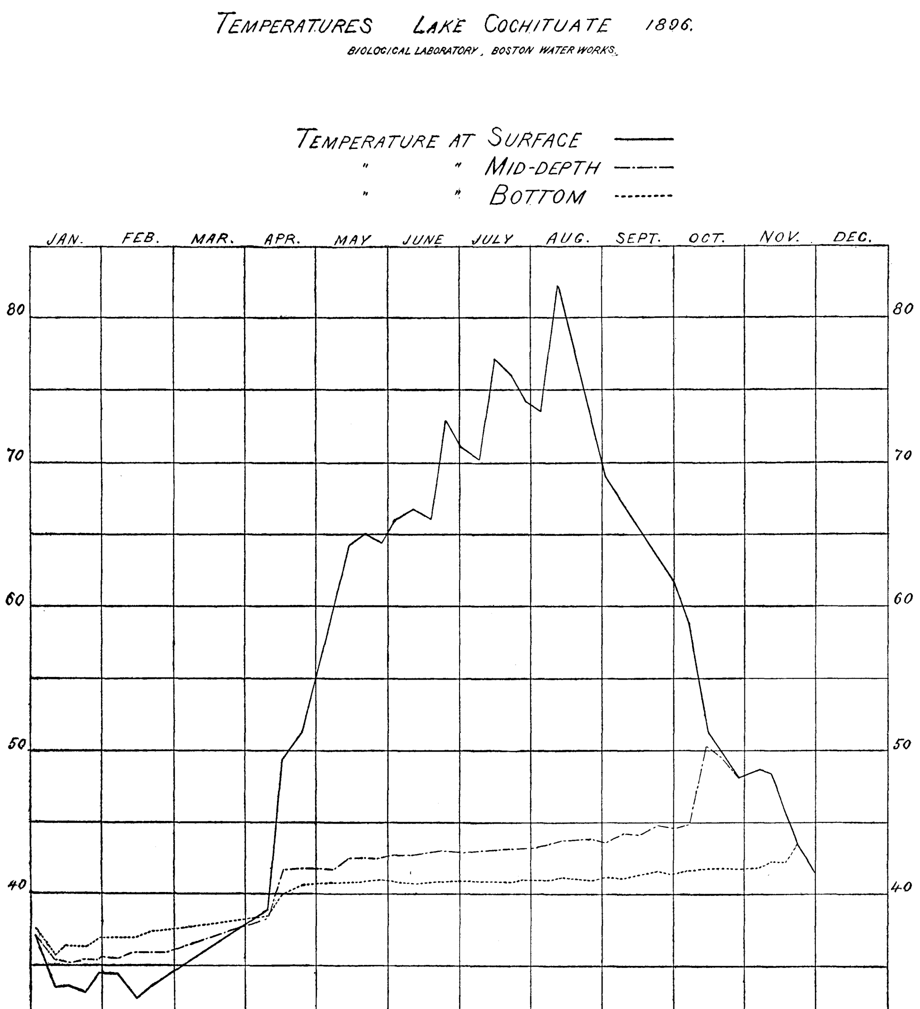
TEMPERATURES LAKE COCHITUATE 1896.
BIOLOGICAL LABORATORY, BOSTON WATER WORKS.
TEMPERATURE AT SURFACE
" " MID-DEPTH
" " BOTTOM
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
80
70
60
50
40
30

PLATE VIII

COLORS LAKE COCHITUATE 1896.

BIOLOGICAL LABORATORY, BOSTON WATER WORKS

COLOR AT SURFACE ————
" " MID-DEPTH —·—·—
" " BOTTOM ------------